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Tin Recycling in the United States in 1998

By James F. Carlin, Jr.

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FLOW STUDIES FOR RECYCLING METAL COMMODITIES IN THE UNITED STATES

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FOREWORD

As world population increases and the world economy expands, so does the demand for natural resources. An accurate assessment of the Nation's mineral resources must include not only the resources available in the ground but also those that become available through recycling. Supplying this information to decisionmakers is an essential part of the USGS commitment to providing the science that society needs to meet natural resource and environmental challenges.

The U.S. Geological Survey is authorized by Congress to collect, analyze, and disseminate data on the domestic and international supply of and demand for minerals essential to the U.S. economy and national security. This information on mineral occurrence, production, use, and recycling helps policymakers manage resources wisely.

USGS Circular 1196, "Flow Studies for Recycling Metal Commodities in the United States," presents the results of flow studies for recycling 26 metal commodities, from aluminum to zinc. These metals are a key component of the U.S. economy. Overall, recycling accounts for more than half of the U.S. metal supply by weight and roughly 40 percent by value.

Charles G. Groat
Director

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CONVERSION FACTORS

	Multiply	By	To obtain
metric ton (t, 1,000 kg)		1.102	short ton (2,000 pounds)
million metric ton (Mt)		1,102,001	short ton

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ABSTRACT

This materials flow study includes a description of tin supply and demand factors for the United States to illustrate the extent of tin recycling and to identify recycling trends. Understanding the flow of materials from source to ultimate disposition can assist in improving the management of the use of natural resources in a manner that is compatible with sound environmental practices. The quantity of tin recycled in 1998 as a percentage of apparent tin supply was estimated to be about 22 percent, and recycling efficiency was estimated to be 75 percent. Of the total tin consumed in products for the U.S. market in 1998, an estimated 12 percent was consumed in products where the tin was not recyclable (dissipative uses).

INTRODUCTION

This materials flow study includes descriptions of trends in consumption, losses, and recycling¹ of tin and tin-bearing materials in the United States in 1998. Of the approximately 76,000 metric tons (t) of tin consumed in fabrication in the United States in 1998, fabrication losses were estimated to be about 1,000 t, or about 1 percent.

Because tin has been one of the higher valued base metals and because the infrastructure to reclaim tin in the United States has been well-developed for many years, tin has had significant recycling rates, though lower than for some other metals. Recycling is especially important for tin because virtually all the domestic primary tin requirements have long been dependent on imports. Historically, the United States has had only a few small tin mines that have supplied a minuscule portion of domestic tin needs. Tin imports and sales of tin from the U.S. National Defense Stockpile have provided most of the Nation's primary tin needs for many years. The reclamation of scrap tin, however, has helped to reduce reliance on the Stockpile and foreign suppliers. The recycling rate for tin was estimated to be about 22 percent in 1998.

In 1998, tin imports in the form of metal or compounds amounted to 44,000 t, and exports of tin metal/compounds were approximately 5,000 t. No data are available on imports or exports of tin scrap. Imports were estimated to be nil, and exports were estimated to be 1 t.

Old scrap consumed was 7,710 t; old scrap recycling efficiency was determined to be about 75 percent; new (prompt) scrap consumption amounted to 8,390 t. The value of this total scrap use was about \$130 million.

Figure 1 shows the domestic flow of tin in 1998 with the flow of recycled tin shown in detail. Figure 2 shows domestic tin usage for the past 20 years.

GLOBAL GEOLOGIC OCCURRENCE OF TIN

Tin is a relatively scarce element with an average abundance in the Earth's crust of about 2 parts per million (ppm) compared with 94 ppm for zinc, 63 ppm for copper, and 12 ppm for lead (Lee and Yao, 1970). Tin is produced from lode (hard-rock) deposits and placer deposits derived from the lodes. The tin mineral cassiterite (SnO_2) is the source of most tin production; a notable exception is the complex tin sulfide minerals in the subvolcanic or tin-silver lode deposits in Bolivia. Cassiterite has a high specific gravity (6.8-7.1) and a Moh's scale hardness of 6 to 7 and is usually a dark-brown or black color with an adamantine luster.

Most lode tin deposits occur as greisen, replacement, skarn, or vein type deposits associated with granitic rocks or their extrusive equivalents where tin has been concentrated by magmatic differentiation processes (Sainsbury and Reed, 1973; Taylor, 1979, p. 1-12). Placer deposits of several types have been derived from lode tin deposits by weathering and erosion. Because cassiterite is heavy and chemically resistant, it is concentrated by weathering in place, which removes lighter minerals (residual placers), or by erosional processes on a slope (eluvial placers) or in streams (alluvial placers). Marine tin placers are formed when tin minerals are concentrated in stream channels or along beaches and then submerged as a result of sea-level changes (Sainsbury, 1969, p. 6-8).

Much of the world's past tin production has been from placer deposits, which generally can be mined more cheaply than lode deposits (Bleiwas and others, 1986, p. 33). From 1934 through 1987, Malaysia, Indonesia, and Thailand accounted for more than one-half of the world's 10 million metric tons of tin production by using major dredge production from marine placer deposits (Sutphin and others, 1990, p. 20).

¹Definitions for selected words are found in the Appendix.

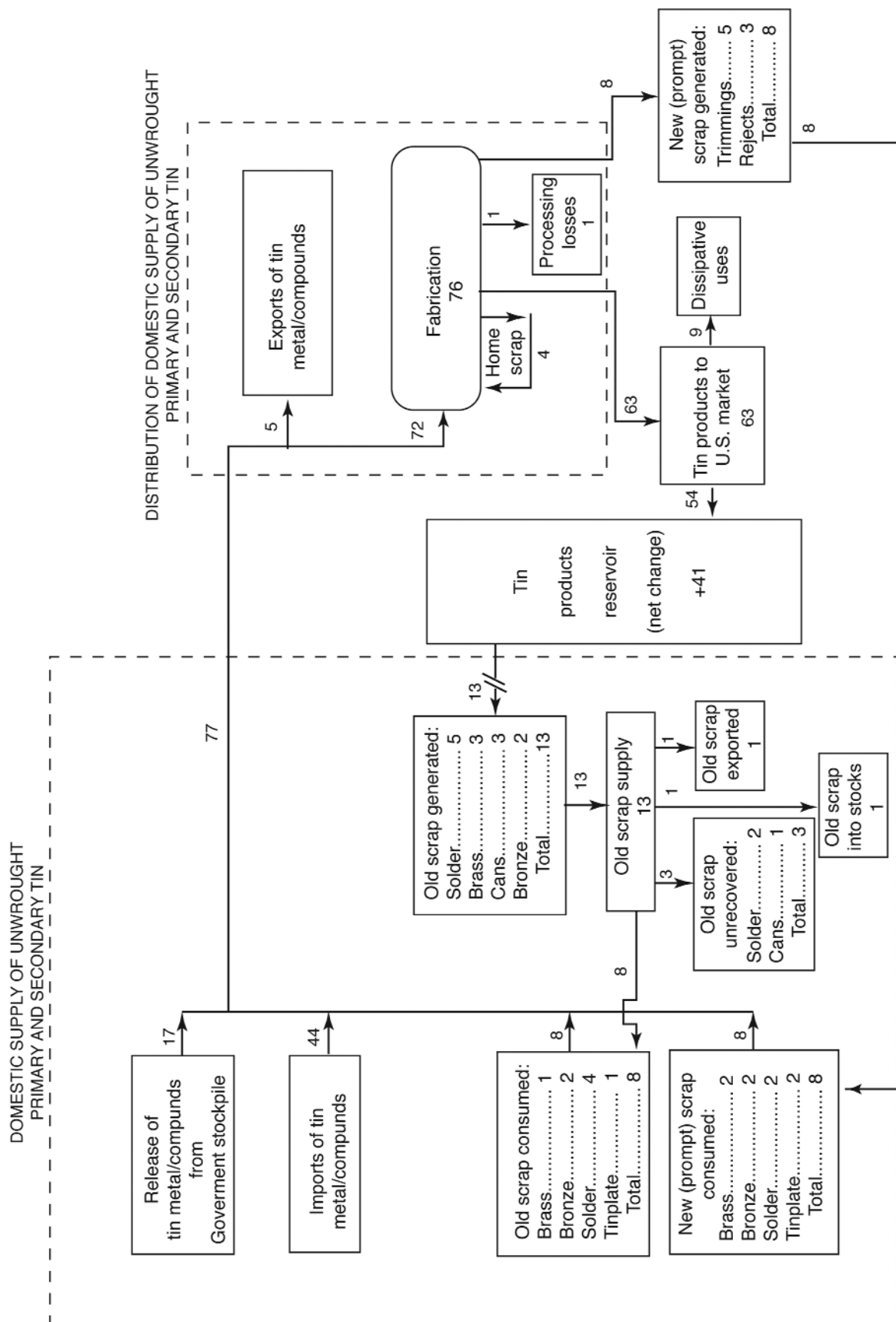


Figure 1. U.S. tin materials flow in 1998. Values are in metric tons contained tin.

Table 1. Salient statistics for U.S. tin scrap in 1998.

[Values in thousand metric tons of contained tin, unless otherwise specified; NA, not available]

Old scrap:

Generated ¹	13
Consumed ²	8
Consumption value ³	\$65 million
Recycling efficiency ⁴	75 percent
Supply ⁵	13
Unrecovered ⁶	3
New scrap consumed ⁷	8
New-to-old-scrap ratio ⁸	50:50
Recycling rate ⁹	22 percent
U.S. net exports of scrap ¹⁰	5
Value of U.S. net exports of scrap	NA

¹Tin content of products theoretically becoming obsolete in the United States in 1998. It excludes dissipative uses.

²Tin content of products that were recycled in 1998.

³Based on tin scrap price, estimated from composite metal prices reported by Platts Metals Week. Values of tin scrap imports and exports are reported by the U.S. Census Bureau.

⁴(Old scrap consumed plus old scrap exported) divided by (old scrap generated plus old scrap imported minus old scrap stock increase).

⁵Old scrap generated plus old scrap imported plus old scrap stock decrease.

⁶Old scrap supply minus old scrap consumed minus old scrap exported minus old scrap stock increase.

⁷Prompt industrial scrap. Some scrap is excluded.

⁸Ratio of quantities consumed, in percent.

⁹Supply fraction that is scrap, on an annual basis. It is defined as (old plus new scrap consumed) divided by apparent supply [primary plus secondary production (old scrap plus new scrap) plus imports minus exports plus adjustment for Government and industry stock changes].

¹⁰Trade in scrap is assumed to be principally in old scrap.

In 2000, China, Peru, and Bolivia accounted for about 63 percent of the world tin production of 200,000 t in 2000 by producing tin from lode deposits. Placer production made up the remaining 37 percent, of which Indonesia accounted for two-thirds (Carlin, 2001b).

World reserve data indicate that China (lode deposits, 26 percent of world reserves), Brazil (placer, 23 percent), Malaysia (placer, 13 percent), and Indonesia (placer, 8 percent) may be expected to play major roles in future tin production. Identified resources of tin in lode and placer deposits in the United States are an insignificant part of world totals (Sainsbury and Reed, 1973). Undiscovered lode tin resources in Alaska's Seward Peninsula, if explored for and discovered, would probably add only modest increases to future domestic production (Reed and others, 1989). Small quantities of tin concentrate have been produced from placer deposits in Alaska and as a byproduct of molybdenum mining in Colorado and New Mexico (Carlin, 1985). The last reported production of tin in the United States was in 1994.

TIN PRODUCTION PROCESSES

Each type of tin deposit has its own characteristic processing technique. The crude tin concentrate from placer mining is upgraded by washing, tabling, and magnetic or electrostatic separation. The final product is virtually pure cassiterite.

Tin ore from lode deposits is reduced to the necessary size by conventional crushing and grinding. The ore is concentrated by gravity methods that involve screening, classification, jigging, and tabling. The concentrate is usually a lower grade than placer concentrate owing to associated sulfide minerals. The sulfide minerals are removed by flotation or magnetic separation, with or without roasting.

Cassiterite in placer deposits is fairly coarse-grained, and recoveries range from 90 percent for gravel-pump mines to 95 percent for dredging operations. The cassiterite in vein deposits, however, is typically very fine grained and is difficult to recover by gravity concentration. Cassiterite ore at lode mines in Australia and Bolivia are floated, but recoveries are seldom above 70 percent. Recovery of the tin content in Bolivia has been reported to be as little as 50 percent (Pearce, 1980, p. 755).

Cassiterite is reduced to tin by heating with carbon at 1,200 to 1,300 C. The almost pure cassiterite concentrate from placer deposits is smelted directly. Other concentrates, particularly from Bolivia, contain impurities that must be removed before smelting. This is usually done by roasting the tin concentrates with or without fluxes and followed by acid leaching. During roasting, most of the sulfur and arsenic are removed as oxides. Bismuth, copper, iron, and zinc oxides are removed by leaching the roasted concentrate with sodium carbonate or sulfate and leaching with water. Antimony, bismuth, lead, and silver are removed by a chloridizing roast followed by an acid leach.

In tin smelting plants, reverberatory furnaces are used to smelt primary tin concentrate and to resmelt slag for additional tin recovery. Blast and electric furnaces are often preferred because of better control, cleaner slags, and superior efficiency in smelting finely divided materials. Electric furnaces may be favored for energy-saving reasons at some operations, especially smaller smelters.

Tin smelting is a batch operation. A typical charge consists of cassiterite concentrate, a carbon reducing agent, and limestone and silica fluxes. Between 10 and 12 hours are required to smelt a charge. When smelting is complete, the molten batch is tapped into a settler from which the slag overflows into cast-iron pots. The molten tin from the bottom of the settler is cast into slabs or pigs for refining (Pearce, 1980, p. 766-768).

TIN MARKET PRICES AND USE PATTERNS

The price of tin is the most important factor that influences its recycling rate. In recent decades, tin generally has been the highest priced base metal. Although almost 20

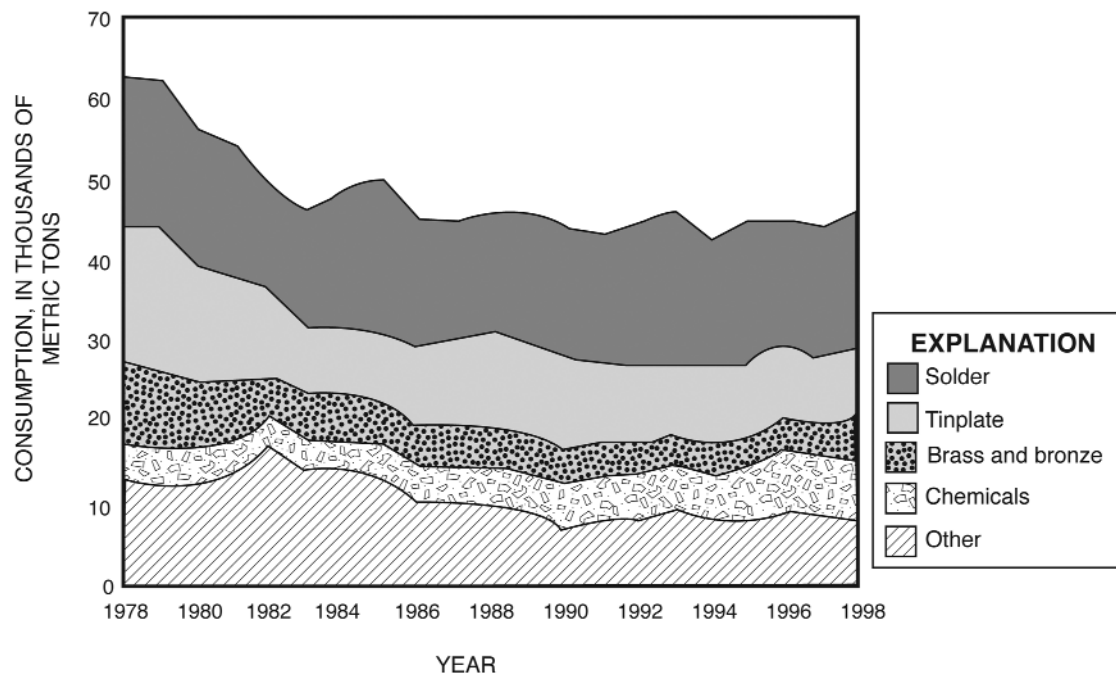


Figure 2. U.S. tin consumption, by end-use sector, from 1978 through 1998.

years have passed since tin reached its historical peak price of more than \$8 per pound, its recent pricing in the \$2.50 to \$4.00 range still provides an adequate incentive to recycle.

The price for tin metal did not vary much throughout 1998. The average composite price for the year, \$3.73 per pound, was 2 percent lower than that of 1997. The London Metal Exchange (LME) was the primary trading arena for tin. Tin was only one of six metals (along with aluminum, copper, lead, nickel, and zinc) to be traded on the LME. The Kuala Lumpur Commodities Exchange in Malaysia, continued as an active tin-trading forum (Platt's Metals Week, 1999).

In 1998, estimated uses of tin in the United States were cans and containers, 30 percent; electrical, 20 percent; construction, 10 percent; transportation, 10 percent; and other, 30 percent (Carlin, 2001b). These tin usage patterns are similar to those in the rest of the world (Carlin, 2000; Roskill Information Services Ltd., 1995, p. 156-170); Figure 2 shows total (primary and secondary) domestic tin consumption by end-use sector between 1978 and 1998.

TIN STATISTICS

Several sources of statistics on U.S. tin materials flow were used in this report to identify recycling parameters as well as the ultimate direction and disposition of domestic secondary supplies. Many of the tin data in this report have been extracted from U.S. Geological Survey (USGS) surveys of all known domestic firms that mine, smelt, use, import, and export tin or engage in scrap-tin recovery. A high percentage of those firms supply data; estimates are made for the

remainder. Most other information in this study that relates to production, supply, consumption, and scrap activity was obtained from USGS publications and industry contacts.

Table 1 and figure 1 present tin scrap data and recycling flow information used in this study.

SOURCES OF TIN SCRAP

Because tin was not produced in the United States in 1998, sources of old scrap and new scrap are key elements of U.S. tin material flow. All scrap tin in the United States is derived from domestic sources; no foreign sources have been reported. In 1998, sources of new scrap and old scrap consumed accounted for equal amounts of secondary tin (8,000 t) in U.S. markets.

OLD SCRAP GENERATED

Old scrap consists of tin-containing products, such as tin cans and electronic equipment, that have been discarded after use. Old scrap is sometimes also referred to as "post-consumer scrap." The old scrap generated in 1998 totaled 13,000 t. Approximately 60 percent of this amount was reused during the year; the remainder was not recovered or was exported or added to industry stocks.

NEW SCRAP GENERATED

New scrap is tin waste that is generated during manufacturing processes and, for the most part, remains the property of the manufacturers; it is continually being recirculated. Home scrap is new scrap that is immediately redirected back into the manufacturing process without leaving the

plant. Some new scrap is collected and later sold to scrap dealers who resell it to similar manufacturers. An example of new tin scrap would be the side trimmings made on a coil of tinplate (tinplate is essentially 99 percent flat-rolled steel with about a 0.5 percent-by-weight flash of tin coating on each side) in a steel mill to meet a customer's width specification; other examples include the tin cans rejected in a canmaking plant owing to poor quality, such as low tin coating weight or insufficient rigidity. In 1998, 8,000 t of new tin scrap was reused, which represented about one-half of the total scrap consumed.

DISPOSITION OF TIN SCRAP

Because of the relatively high value of tin compared with other base metals, such as copper, lead, and zinc, the domestic tin consuming and tin recycling industries have become more efficient in recapturing discarded tin products. Also, because of its value, tin often been the target of smuggling attempts in areas that range from tin smelter sites in developing countries to scrapyards sites in the United States. Smuggling has been especially prevalent at times when tin prices reached high levels. Tin has generally been considered to be a nontoxic material. Thus, environmental considerations are not major factors in recycling.

OLD SCRAP RECYCLING EFFICIENCY

The recycling efficiency of old tin scrap is substantial despite the fact that its recycling rate is relatively low. Old scrap recycling efficiency, which is the amount recovered and reused relative to the total amount of old scrap generated and theoretically available for recycling, was 75 percent in 1998, whereas the recycling rate was 22 percent. The lower recycling rate was partly due to the fact that the third leading use for tin (tin chemicals) has end uses that are nearly all dissipative.

INFRASTRUCTURE OF TIN SCRAP INDUSTRY

Tin has not been mined in the United States for several years. During the past decade, a few small tin mines, most of which are in Alaska, have satisfied only a small fraction of domestic demand. TexTin Corp., which was the only domestic tin smelter, operated for decades in Texas City, Tex.; it closed in 1989 because it was unable to economically compete for foreign tin concentrates. For most of its history, the United States has depended on tin imports, Government stockpile sales, and recycled tin scrap for its industrial requirements (Defense National Stockpile Center, 1998).

In 1998, scrap tin was generated domestically at 5 detinning plants and 46 secondary non ferrous-metal-processing plants. Old tin scrap was collected at hundreds of scrapyards, the five detinning plants, and most municipal

collection-recycling centers. New scrap was generated mainly in the tin mills at six steel plants and at scores of canmaking facilities. Most tin-scrap-processing plants are close to tin-using industries in major market areas, most of which are in the Midwest and the Northeastern United States.

Detinning facilities are unique to the tin scrap industry because no other major metal industry has numerous large-scale plants designed to remove metal plating. Detinning operations are performed on new tinplate scrap from tin mills and canmaking plants and from old scrap in the form of used (postconsumer) tin cans.

The domestic metals recycling industry, as a whole, has been undergoing substantial consolidation during the past 30 years. Before consolidation, the industry was characterized by a multitude of small, family-run firms, many of which dated back to the 19th century. Usually, the firms operated only locally or perhaps regionally. From 1970 onward, however, the industry has been characterized by fewer, larger units that serve national or international markets.

The Steel Recycling Institute (SRI), which is funded by the Nation's major steel producers, has promoted the recycling of used tin cans for more than a decade. These used tin cans have become an important raw material for the domestic steel industry during the past 20 years. According to the SRI, the steel can recycling rate had grown to 56 percent in 1998 from 15 percent in 1988. The increased recycling is significant to tin recovery because most steel cans are made from tinplate (Steel Recycling Institute, 1999).

Major domestic tin requirements have long been met by imports of primary refined tin. In recent years, Brazil has generally been the leading source followed by Indonesia, Bolivia, and China. Trade in tin scrap is relatively small, and trade figures are not available. No imports of tin scrap in 1998 were identified. The United States exported relatively small quantities of new and old tin scrap.

PROCESSING OF SCRAP METALS

Typically, the alloys of tin, such as brass and bronze, jeweler's metal, or babbitt, contain from 2 percent to 11 percent of tin as a minor component of the alloy. The major exception is solder. Solders for plumbing and construction-related uses have traditionally been 50 percent tin-50 percent lead, and those for electronics have usually been 70 percent tin-30 percent lead. The bulk of the secondary tin industry processes various alloy forms of tin (brass, bronze, and solder); the recovered tin is recycled within its own product-line industries and, thus, is used again in alloys. The scrap materials of all alloys of tin are collected via long-established commercial routes and transported back to the original makers of the alloys. Typically, these alloy producers then use a mix of primary tin along with the primary element(s) of the other component(s) of the alloy and com-

bine them in a batch heating process with the collected scrap materials to produce new units of the same alloys. Thus, the secondary tin industry is essentially involved in a process of successive regeneration with old and new scrap alloys being mixed with some primary material added for each new generation of alloys.

For most of this century, detinning has been the only process in the secondary tin industry through which tin alone, not in alloys, reached the marketplace. Consequently, detinning of tinplate is one of the most important sources of tin scrap in the United States. Tinplate scrap suitable for detinning is accumulated at various stages—off-specification tinplate generated in the tin mills at steel plants, reject tinplate and tin cans generated at canmaking facilities, reject cans at can-filling operations, and old scrap tin cans collected by municipalities via curbside collection programs. These collected forms of new and old tinplate scrap are transported to five domestic detinning plants. There, they are immersed in a heated sodium hydroxide solution, which is a batch process that is essentially the reverse of the original tin electroplating process. Tin ions leave the steel surface and migrate to an electrically charged cathode where they deposit and form a bar of tin. The detinned steel is then sold to scrap steel markets, most notably to be used as a scrap charge in the electric furnaces of steel minimills. The bars of scrap tin are then sold to appropriate users of secondary tin, such as producers of tin chemicals, firms that use tin to hot dip onto copper wire, makers of brass and bronze ingots, and the vast number of manufacturers of tin alloy. Traditionally, scrap tin is not used to make tinplate because of purity requirements. The tin coating thickness on steel in modern tinplate is only about, on average, one-half to one-third of what it was in the early 1960s. Today, the nominal tin coating thickness on each side of tinplate is only 0.000381 millimeters. Thus, the economics of detinning make it not nearly as profitable as it once was. Nevertheless,

for maximum steel cleanliness, some steel producers prefer to pay more to have tinplate scrap detinned before they use it; the presence of tin on the surface of scrap steel often is considered to be a major detriment to good quality steel (Groetsch and others, 1984).

OUTLOOK

The established stable consumption pattern of tin and the relatively high price of tin compared with that of other base metals indicates that plentiful amounts of tin will be available for recycling in future years. Moreover, the almost total U.S. reliance on tin imports, the planned elimination of Government tin stocks, and the expected technological advances will tend to encourage more recycling of tin in the next few decades. In addition, the United States will, most likely, continue to be the leading source of scrap for domestic tin markets. Except for dissipative uses, tin scrap for recycling will continue to come from all consumption sectors. Tin prices probably will remain as the most important influence on further recycling advances (Carlin, 1985; Roddy, 1995, p. 84-85).

Trends toward consolidation in the recycling industry are expected to continue, at least in the near future. The resulting larger enterprises presumably will be able to attract funds more easily for equipment modernization and technological improvement that often lead to lower unit processing costs. Thus, consolidation trends augur well for increased recycling of tin. The recycling of tin enhances the sustainability of tin production by reducing the need for primary production, thereby saving energy and extending the longevity of natural resources. The prospects for increasing the recycling rate for tin chemicals are not particularly good, however, because tin chemicals are mostly a dissipative end use. Additionally, some of the more promising new uses for tin, such as ammunition, are essentially dissipative (Carlin, 2001a).

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APPENDIX—DEFINITIONS

apparent consumption. Primary plus secondary production (old scrap) plus imports minus exports plus adjustments for Government and industry stock changes.

apparent supply. Apparent consumption plus consumption of new scrap.

dissipative use. A use in which the metal is dispersed or scattered, such as paints or fertilizers, making it exceptionally difficult and costly to recycle.

downgraded scrap. Scrap intended for use in making a metal product of lower value than the metal product from which the scrap was derived.

home scrap. Scrap generated as process scrap and consumed in the same plant where generated.

new scrap. Scrap produced during the manufacture of metals and articles for both intermediate and ultimate consumption, including all defective finished or semifinished articles that must be reworked. Examples of new scrap are borings, castings, clippings, drosses, skims, and turnings. New scrap includes scrap generated at facilities that consume old scrap. Included as new scrap is prompt industrial scrap—scrap obtained from a facility separate from the recycling refiner, smelter, or processor. Excluded from new scrap is home scrap that is generated as process scrap and used in the same plant.

new-to-old-scrap ratio. New scrap consumption compared with old scrap consumption, measured in weight and expressed in percent of new plus old scrap consumed (for example, 40:60).

old scrap. Scrap including (but not limited to) metal articles that have been discarded after serving a useful purpose. Typical examples of old scrap are electrical wiring, lead-acid batteries, silver from photographic materials, metals from shredded cars and appliances, used aluminum beverage cans, spent catalysts, and tool bits. This is also referred to as postconsumer scrap and may originate from industry or the general public. Expended or obsolete materials used dissipatively, such as paints and fertilizers, are not included.

old scrap generated. Metal content of products theoretically becoming obsolete in the United States in the year of consideration, excluding dissipative uses.

old scrap recycling efficiency. Amount of old scrap recovered and reused relative to the amount available to be recovered and reused. Defined as (consumption of old scrap (COS) plus exports of old scrap (OSE)) divided by (old scrap generated (OSG) plus imports of old scrap (OSI) plus a decrease in old scrap stocks (OSS) or minus an increase in old scrap stocks), measured in weight and expressed as a percentage:

$$\frac{\text{COS} + \text{OSE}}{\text{OSG} + \text{OSI} + \text{decrease in OSS or} - \text{increase in OSS}} \times 100$$

old scrap supply. Old scrap generated plus old scrap imported plus old scrap stock decrease.

old scrap unrecovered. Old scrap supply minus old scrap consumed minus old scrap exported minus old scrap stock increase.

primary metal commodity. Metal commodity produced or coproduced from metallic ore.

recycling. Reclamation of a metal in usable form from scrap or waste. This includes recovery as the refined metal or as alloys, mixtures, or compounds that are useful. Examples of reclamation are recovery of alloying metals (or other base metals) in steel, recovery of antimony in battery lead, recovery of copper in copper sulfate, and even the recovery of a metal where it is not desired but can be tolerated—such as tin from tinplate scrap that is incorporated in small quantities (and accepted) in some steels, only because the cost of removing it from tinplate scrap is too high and (or) tin stripping plants are too few. In all cases, what is consumed is the recoverable metal content of scrap.

recycling rate. Fraction of the apparent metal supply that is scrap on an annual basis. It is defined as (consumption of old scrap (COS) plus consumption of new scrap (CNS)) divided by apparent supply (AS), measured in weight and expressed as a percentage:

$$\frac{\text{COS} + \text{CNS}}{\text{AS}} \times 100$$

scrap consumption. Scrap added to the production flow of a metal or metal product.

secondary metal commodity. Metal commodity derived from or contained in scrap.